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A paper trail of evaluation approaches to energy and climate policy interactions

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ABSTRACT

Focal point of this review is to provide a comparative display of qualitative and quantitative methodologies employed for the appraisal of interacting energy and climate policies, underlying their key features while presenting the most critical issues and limitations not addressed so far. Qualitative approaches provide a descriptive explanatory analysis of often non-quantifiable process in policy interactions, whereas modeling approaches provide numerical data estimating the extent of policy interaction impacts. Quantitative methods work best for narrowly specified policy combinations, while contextual implications and cause-impact effects are explained further via qualitative ones. In addition most evaluations so far adopt a rational view of policies and policy interactions leaving out a systemic evaluation of the institutionalism of interacting policies. Research analysis of energy and climate policy interactions is still young in comparison to the broad field of policy evaluation and impact assessment. However infants inherently tend to grow. Endeavors for a methodological framework that would allow for a systematic exchange of data between qualitative and quantitative approaches and would also include the relevance of the context as well as key casual relationships behind policy combinations, would provide the basis for further growth of knowledge in the field.

Contents

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1. Introduction

Researchers and policy makers face formidable obstacles in seeking to understand, let alone analyze, the impacts of environmental, economic and social features of energy and climate policies. It gets worse by adding inherent difficulties such as irreversibility, data scarcity and uncertainty, non-linear behavior and multiple (usually conflicting) objectives. To this respect an array of methodologies and tools are employed in an effort to incorporate as many underlying features of energy and climate policy instruments bound to affect their impacts, as well as associated barriers. Literature provides a range of methodologically diverse techniques (e.g. case studies, survey research, statistical analysis, model building, etc.) assessing mainly the operational effects of single energy and climate policy instruments, or parallel comparisons of those, for the most part, emissions trading schemes with taxes or additional instruments ([50,11,31,30,45,46,51]). However policies always come in a mix [13] and therefore need to be assessed in that fashion. Recent studies are seeking to provide an integrated assessment of energy and climate policy interactions and they have applied varying methodologies setting different focuses ([20,22,41]). In addition, studies reviewing research on interacting policies have so far been mainly concerned with static and dynamic sustainability impacts of combined policy instruments upon a regulated market system and potential conflicts among findings ([11,13], [41,22,23]). At the same time the need for an improved methodological framework for ex-post and ex-ante assessment of energy and climate policy mixes in a realistic policy interactions environment is highlighted [6,8,34]. Taking into consideration the above-cited situation, we explore recent representative paradigms of evaluation approaches and methodologies aiming to provide a critical display of the latter in relation to their research focus and view on interactions, while presenting the most critical issues not addressed so far. In doing so we prefer to classify those into the broad categories of qualitative, quantitative and hybrid evaluation approaches in an attempt to provide a comparative overview of their underlying dimensions. A unified framework is henceforth adopted, leaving out studies assessing or comparing single types of policies. The review was conducted within the framework of the EC FP7 project “Assessment of Policy Interrelationships and Impacts on Sustainability in Europe” (http://www.apraise.org), whose objective was to empirically assess the existing and planned environmental policies in selected sectors of EU Member States and expand the existing databases on multiple parameters of environmental policies.

The rest of this paper is structured as follows. Section 1 provides an introduction to the background in recent work on climate and energy policy interactions while the assessment framework is introduced in Section 2 upon which the review is structured. Section 3 provides an analytical outline of evaluation approaches and different evaluation means (i.e. methods) in the area of energy and climate policy interaction evaluation. A cross comparison of the different approaches in conjunction to their methods and views on policy interactions is presented in Section 4. Section 5 examines those approaches with respect to their impact focus and identified explanatory factors behind their impacts. Finally Section 6 provides an overview of the underlying dimensions each approach brings forward in the evaluation of energy and climate policy interactions, leading to concluding remarks and directions for future research.

2. A unified assessment framework

Instead of concentrating on the ensuing outcomes of research so far, our scope is rather to present in parallel different types of evaluation approaches in relation to their research focus and their underlying methodological components. Like so, principal issues not adequately addressed yet in policy interactions appraisal and impact assessment are highlighted along the evaluation dimensions as set out below.

Drawing upon Peter Hall's [18] three-fold division of policy into elements we consider a policy to comprise the overall objective that drives policy interventions, the policy instruments by which these policy objectives[1] are achieved and the design characteristics of these instruments that determine their functioning and implementation. Throughout the review we thus consider that policy interactions can be observed and assessed at two basic levels.

- Policy instrument level: interactions effects can be identified at the level of policy instrument goals and/or due to their specific policy design provisions ([18]). In other words interaction of policy instruments may occur when the targets or design characteristics of a policy instrument may affect the functioning or result of another policy instrument.
- Market/stakeholders level: policy instruments may interact due to stakeholders' response to their concurrent implementation, which is often driven by conflicting interests and objectives [48].

Research in the field of climate and energy policy interactions has henceforward been structured under the two main themes of

(i). Different evaluation approaches and primary methods employed in relation to their view on energy and climate policy interactions (i.e. interaction levels as discussed in Section 2).
(ii). Impact focus, looking at what aspects of the performance of an integrated policy mix, has been assessed so far and to what extent, as well as which explanatory factors behind those impacts have been identified.

2.1. Impact focus of evaluation approaches

Departing from the empirical work conducted within INTERACT project [54] and previous research on policy interactions and impact-assessment [6,31,42], the points of reference in our review, regarding the impact focus (i.e. objectives) of recent literature in the area of interacting policies, are the following three performance criteria:

- *Effectiveness:* Evaluating the effectiveness of a (set of) policy instrument(s) demonstrates the extent to which its intended impacts were attained. Effectiveness therefore refers to attaining desired by the policy makers, targets [40,11]. Underlying dimensions in the assessment of effectiveness entail the environmental performance, social effectiveness and economic opportunities and competitiveness that a (set of) policy (instruments) can bring about.
- *Efficiency:* The efficiency of a policy or mix of policy instrument (s) contemplates its desired effects against its estimated or realized costs. Distinguishing among static and dynamic efficiency, we underline static efficiency as the ability of a policy instrument of target achievement under the constraint of burden sharing across firms/plants/agents. Dynamic efficiency refers to the ability of an instrument to generate a continuous incentive for technical improvements and costs reductions in technologies [11].

[1] Throughout the review, for means of simplification we consider a policy objective to be translated into policy instrument targets guiding the operation of policy instruments.

– *Efficacy* refers to the direct impact of policy cycle activities of one or a set of policy instruments compared to the baseline case (i.e. stand alone policy instruments or no policy instruments at all). In other words the efficacy of a (set of) policy instrument(s) refers to its potential impact that was intended (and expected) by the policy makers involved in its design and initiating its implementation [48].

The difference between potential goal attainment and effectiveness lies in the causal role of policy [62,7], rendering the meticulous evaluation of policy effectiveness essential. When having to decide on the most appropriate new policy instrument, the option should be based primarily on the efficacy of the instrument [60]. In addition, when it comes to earmarking environmental tax revenues for funding purposes, their efficacy should regularly be revised [40]. In other words, determining whether a policy instrument, let alone overlapping ones, is able to achieve their intended effects, becomes a pre-condition before addressing the overall performance of the policy mix.

The potential policy outcome may differ widely depending on the occurrence or lack of favorable or impeding factors. It is rather the way these instruments are designed and implemented, or even the context in which they are developed, which can be attributed to its potential impacts [50]. We thus argue that in a step-wise performance assessment of policy mixes, the first step to deal with should entail the efficacy of a policy mix (see Fig. 1). Explanatory factors (i.e. efficacy factors) behind the impact of a (set of) policy instrument(s) can result from

1. Broader contextual factors related to the economic or political context that may evolve differently than expected and can thus favor or hinder the intended course and effect of a (set of) policy instrument(s),
2. The implementation procedure of a policy instrument within a policy mix that was hindered or facilitated unpredictably.

As such, research approaches are reviewed with specific consideration to the performance criteria and aforementioned evaluation aspects listed above in order to describe their impact focus and more importantly to explore explanatory factors behind their impacts.

2.2. Classification of evaluation approaches to energy and climate policy interactions

Policy instruments addressing energy and climate challenges can be characterized by high complexity levels due to their usually compound design details that are not easily understood by relevant stakeholders. It is also the case that the formulation of such policies is quite often affected by the objectives of various groups of stakeholders and their ability to influence the final process of policy design. As a result their launch and implementation is followed by a series of cause impact relationships driven by different actors with usually conflicting interests [19,38]. Hence on the basis of the abovementioned distinction on different evaluation views on policy interactions (i.e. interaction levels), we seek to find what evaluation approaches and methods have been employed to elucidate cause impact relationships behind policy interaction as well as market-relationships affected.

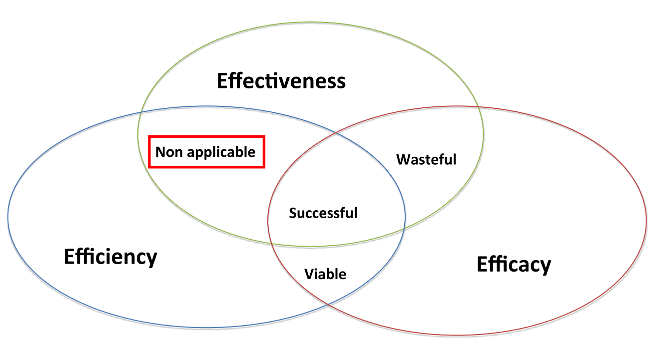

Fig. 1. The core performance indicators of a policy or policy mix (source own elaboration).

This review is concerned with approaches and supporting methods identified within overarching evaluation designs. An evaluation design refers to the primary logic of how research is conducted [29]. We have focused on the different approaches and complementary methods that support assessments of energy and climate policy interactions.

According to Crabbé and Leroy [7] there are several approaches to the evaluation of environmental policy (e.g. need analysis, program theory evaluation, experiment and quasi-experiment, impact assessment, cost effectiveness analysis and cost to benefit analysis, multicriteria analysis, etc.). The list of approaches presented here is by no means exhaustive but instead it provides key diverse approaches, methods and techniques of environmental policy assessment that have been applied to investigate energy and climate policy interactions in current literature.

Different evaluation designs may share similar approaches and methods. In addition some methods tend to adopt a more simple and straightforward mode not being able to employ all the stages of an incumbent methodological framework (e.g. multicriteria analysis, cost benefit and cost effectiveness analysis) while others tend to comprise of a combination of approaches supporting and supplementing each other's results [15,11,46,47]. What keeps them together is the overarching logic of a design framing different approaches and methods employed.

We structure the overall assessment of approaches applied so far by classifying those into three underlying categories based on the type of data each one of them employ and elaborate upon that is to say qualitative, quantitative and hybrid assessment designs. We consider an evaluation design dealing with numerical data, employing a modeling framework to result in a calculative description, as a quantitative evaluation design, whereas qualitative evaluation designs are considered the ones resulting in explanatory descriptions (i.e. prose or textual forms) allowing for qualitative estimations and empirical observations [7] (Fig. 2).

The distinction is important as it maintains attention on the complementary methods and techniques employed to address policy interactions, within each evaluation design. A parallel overview of those approaches and methods in relation to their different views on policy interactions enables a better understanding of what pieces in the puzzle of evaluating energy and climate policy interactions are addressed by each approach (see Section 5).

Finally, in an effort to demonstrate the underlying difference among qualitative and quantitative evaluation approaches, regarding the evaluation timeframe they adopt, we classify the impacts upon a regulated subject as well as upon the surrounding market system in intratemporal evaluation time frame, intertemporal short to midterm and intertemporal long term evaluation timeframe. An intratemporal evaluation time frame is used when the study only provides a static picture of the interacting system among policies in the market area, intertemporal short to midterm evaluation timeframe is considered when the research provides a short to medium term forecast of the way coexisting policies in the system are evolving and lastly intertemporal long term when the researcher allows for a long term forecasting vision of policies coexistence and their respective impacts on the market forces.

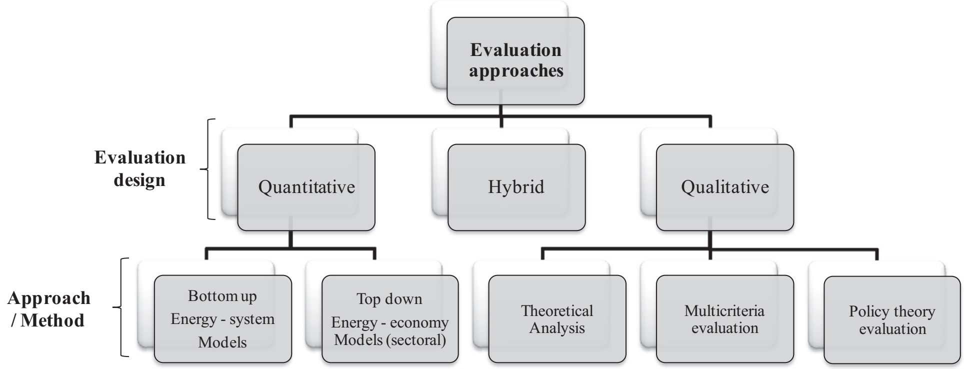

Fig. 2. Classification tree of evaluation approaches to energy and climate policy interactions.

3. Evaluation approaches and methods addressing energy and climate policy interactions

The radically increased policy-makers awareness of the issue of overlapping policies has initiated a growing number of energy and climate policy interaction studies [6]. This study is intended to provide an overview of approaches in the field; therefore we do not provide an exhaustive description of the latter. We rather describe a limited number of representative evaluation approaches to illustrate the present state of the art in energy and climate policy interactions appraisal.

3.1. Quantitative evaluation approaches

Energy models able to deal with combinations of policy instruments have already been applied [2], as economists and policy makers acknowledge the fact that policies have begun to pile up and interact in complex ways [6,34]. Jebaraj and Iniyan [25] provide a thorough review on energy models. Within the scope of our review of quantitative approaches addressing energy policy interactions, two major clusters have been distinguished: bottom up energy system models and top down sectoral modeling approaches. The latter concentrates on the interactions of the energy sector with the rest of the economy. On the contrary bottom-up energy system models usually focus on the energy sector entirely, and apply highly disaggregated data to describe thoroughly energy end-uses and technology production options to meet energy demand [59]. Different types of bottom up energy system models have been applied to investigate energy and climate policy interactions. The MARKAL bottom-up energy system model has been widely used to investigate energy system implications regulated by renewable and/or climate change policies in different countries. Kannan and Strachan [28] and Strachan et al. [57] have examined the cost-effective technology and energy mix under binding CO_2 reduction targets. The MARKAL elastic demand (MED) variant was applied by Anandarajah and Strachan [2] to assess the impacts of different renewable support policy instruments upon long-term carbon reduction targets. Demand functions in the model determine how each energy service demand varies as a function of the market price and the elasticity parameter of that energy service. Götzz et al. [17] used the integrated MARKA-EFOM system to examining the coexistence of the German Feed in Tariff (FiT) system with the Emissions Trading System (ETS). The FiT system was endogenously modeled by integrating the tariffs directly in the model and by assigning the corresponding levy to the end-use electricity prices through an iterative process of several model runs.

Top-down modeling evaluation approaches used to examine interactions in the energy and climate package usually consists of input–output models, or computable general equilibrium (CGE) models. As such, Morriss [37] applied a top down CGE energy system (emissions prediction and policy analysis) model to assess the same set of renewable portfolio standard (RPS) scheme in the U.S. market and a cap and trade (C&T) scheme and their effects on economy wide sectors. Each generation technology was represented by a constant elasticity of substitution (CES) production function input vector of capital, labor and fuel.

Tsao on the other hand, uses less technological details of the energy system and more aggregated data when analyzing the interactions of the markets in the co-existence of the same policy combination, a C&T and a RPS scheme Tsao [58]. In this case the top down approach emphasized on the comprehensiveness of endogenous market adjustments. Three types of power producers (coal, natural gas, and renewable producers) who face price-responsive electricity demand were considered. Similarly, a top down generation expansion planning (GEP) model based on game theory was also employed to assess the performance of a C&T scheme and four modifications of carbon tax policies and their resulting impacts upon new investments in renewable energy generation capacity (He et al. [20]. A group of generating companies competes in a Nash–Cournot manner to maximize their own profits by generating and selling electricity in a bilateral market under different policy constraints and additional costs imposed. In this way policy impacts on utilities' generation expansion planning decisions are quantified within a competitive electricity market.

Identified strengths and weaknesses between the two quantitative approaches explain the wide range of mixed modeling approaches also in the field of renewable and climate change mitigation policy interactions appraisal [21]. Abrell and Weigt [1] combined both top down and bottom up analytical views by using a CGE model to examine the interactions of the coexistence of an ETS and a Fit system for large offshore wing generation in the German electricity market. Each technology was characterized by a Leontief unit input vector of capital, labor, and fuel input associated to base, mid, or peak load. Similarly Linares [35] used a GEP model for the Spanish power sector to examine the interaction effects between tradable green certificates (TGC) and the emissions trading scheme (ETS) on the electricity utility operation, and expansion planning investments. He focused on incorporating oligopolistic firm behavior while also including disaggregated data to realistically describe energy end-uses and technological options of the Spanish power sector. He demonstrated that under oligopoly, different results are obtained when incorporating the allowance price into the price of electricity compared to a perfect competition assumption.

3.2. The use of theoretical economic models in energy and climate policy interactions appraisal

A number of studies have also examined the impacts of the coexistence of climate change and energy policies on the market

by applying top down theoretical models that allow market equilibriums to be solved analytically, without however including case-study based numerical simulations ([16,32,33,12,56]). Theoretical economic models represent economic processes by a set of variables and a set of logical and/or quantitative relationships between them. Such econometric models are generally used in ex-ante impact assessment of interacting policy instruments, providing a simplified framework designed to demonstrate complex processes, often but not always incorporating mathematical techniques and structural parameters [61]. Bohringer and Rosendahl [4], focusing on the relative stringency of a C&T scheme with a RES obligation[2] concluded that the excess cost of imposing a green quota on top of a C&T scheme can be quite substantial and that emission levels might also be increased.

Simplifications in important market and technology details when representing supply and demand analysis enable those approaches to turn their focus on representing different design characteristics of policy instruments. Thus the importance of such design features in the final outcome of the combined implementation of policy instruments is underlined. Like so, Fankhauser et al. [12] focused on the trading option of climate change policies in various combinations with other renewable & climate policy instruments to achieve a given environmental target. He concluded that a thorough design of such policy instruments is imperative in order to guarantee that such policy instruments only target market failures of an incumbent ETS system such as energy efficiency and innovation and avoid carbon policy redundancy. A similar argumentation was made by Gawel et al. [16] based on a stylized theoretical model, to prove their case that, renewable energy policies may contribute to a more effective ETS-design increasing the efficiency of the policy mix, provided that other externalities and policy objectives besides climate protection are considered.

Oikonomou et al. [42] addressed, a more neglected by most quantitative approaches combination of policy instruments, that of climate change and energy efficiency policy instruments. The authors used a theoretical economic model to analyze the behavior of energy producers and suppliers under different market conditions. They concluded that different sorts of taxation when combined with a white certificate scheme (WhC) lead electricity suppliers to different optimizing behaviors. Likewise, Lecuyer and Ribas expanded the microeconomic theoretical model used by Fischer and Preonas [13] to include two energies and the energy-efficient goods, produced by representative producers, satisfying profit-maximization programs. By differentiating the market equilibrium equations, they produce prince and energy quantity derivatives, based upon which they give formal definitions of synergistic and antagonist effects in the model.

Overall such theoretical models point out to possible developments, since their empirical plausibility is questioned. However they tend to provide a more explanatory analysis under a quantitative evaluation framework of interacting policies by examining various, usually untapped, combinations of the latter. While also drawing attention on critical issues in policy design and their influence over the final outcomes of the integrated policy mix.

3.3. Qualitative evaluation methodologies

Qualitative research is considered to probe those relationships, that quantitative analysis can describe by producing data and predict how those will evolve, and to explain contextual differences in those relationships [14]. Qualitative design approaches applied to evaluate interacting policies tend to focus on their simultaneous implementation and conditions under which a policy package is functioning or not. Therefore approaches applied such as theory-based evaluation or conceptual analyses tend to evaluate whether the interacting policies are effective in terms of whether they impede or facilitate their joint implementation [7].

Most qualitative approaches reviewed examining overlapping instruments incorporate more than one basic method or technique. Del Rio [11] provides a conceptual incentive analysis while also evaluating policy instruments' design elements within a multicriteria framework. These types of qualitative assessments vary significantly with respect to the focus of each research and they are defined in a broader manner. We attempt to classify such studies on the grounds of their central methods applied which can be clustered under theoretical–conceptual analysis, multicriteria and theory-based evaluation, while considering additional techniques as supporting appraisal methods. A brief description of the denotations we give for each technique within this review will assist classifying and assessing them.

Multicriteria evaluation has been applied in energy and climate policy impact assessment widely evaluating different policy options (see among others, Ragwitz et al. [50]; Del Rio [10]; Konidari and Mavrakis [31]). However the majority of papers addressing interacting policy instruments apply a more simple approach of multicriteria evaluation, investigating how the impacts of the interactions between those instruments affect a number of criteria and variables [11].

Based on the principles of multicriteria analysis, studies assessing interacting policy instruments provide an evaluation framework consisting of various criteria and diverse variables against which the impacts of alternative policy instruments are evaluated and compared. INTERACT project [54] was based upon an ex-ante explanatory analysis of interactions supported by empirical findings and ex post observations providing a common framework for comparing different policy options. Based on empirical evidence the appropriateness of alternative policy combinations was evaluated within a multicriteria framework against a numerical scale from 1=poor to 5=good that allowed for a semi-quantitative evaluation. Similarly, Del Rio [11] evaluated how different design elements affect those impacts against a set of three criteria, namely, effectiveness, cost effectiveness and dynamic efficiency. Multi-criteria based evaluation also allows for participatory analysis but is subject to caveats such as subjectivity and value-laden findings. As such Oikonomou et al. [44] forms a decision support tool to assess the coexistence of EE support policy instruments and taxation policies. The key notion is that policy makers state their preferences, both when it comes to different design elements of policy instruments (i.e. by stating the respective significance in a merit order), as well as to assessment criteria of pair-wise instruments (i.e. by assigning weighting factors); shaping in this way the outcome of policy interactions.

Policy theory evaluation has also been one of the main contributors in current research investigating interaction among policy instruments. In other words, theory-based policy evaluation establishes a rational theory on how a policy instrument was intended to reach its objectives while also accounting for its interrelationships with other policy instruments in the policy mix. Like so, Harmelink et al. [19] addressed interrelationships of EE promotion policy instruments, in terms of identifying cases of essential policy combinations and cases of policy redundancy, while drawing the theory of all steps in the implementation process of identified energy efficiency policy instruments.

The last cluster of qualitative methodologies, namely conceptual analysis, is considered to refer to a variety of qualitative approaches employed in the field of policy interactions all presenting a rather abstract, theoretical analysis that elaborates upon

[2] The RES obligation, in other words green quota, requires a binding share α of total power production to be covered from renewables.

the various impacts of interacting policy instruments upon a number of prime variables. In most cases graphical techniques support the conceptual approach, strengthening the resulting estimations and observations while allowing for a more detailed appraisal of alternative design elements included in the functioning of policy mixes [56,11].

3.4. The use of hybrid methods in the evaluation of energy and climate policy interactions

Many scenario studies using energy models, cope with combinations of policy instruments; however their effects due to their simultaneous implementation are hardly treated explicitly. According to Sorrell et al. [54], interaction analysis still calls for a systematic approach and new methods to investigate policy interaction effects, both in a quantitative and a qualitative manner, are required [6].

Piet Boonekamp used a qualitative matrix for addressing all different combinations of past energy efficiency policy instruments implemented in the Netherlands. His qualitative analysis was based on characteristics of the implementation process and on reported effectiveness of combinations of policy instruments in practice leading to an identification of the most important interacting combinations of those. Quantitative insight into those interaction effects in the past was gained through a bottom up energy simulation model employed for the selected policy instruments for household energy efficiency in the Netherlands for 1990–2003. In the same fashion, De Jonghe et al. [8] applied a simulation model to quantitatively assess the effects of the coexistence of an ETS and a RPS scheme on renewables deployment and CO_2 mitigation, demonstrated originally through graphical analysis. Then a regional simulation model was applied to represent France, Germany and Benelux, enabling for a comparative analysis of impacts and interactions of policy instruments implemented in regions with significantly conflicting features. Bohringer et al. [5] also used a graphical equilibrium analysis to develop an analytical framework, which was then translated into a numerical multi-regional partial equilibrium model of the EU ETS carbon market. The quantitative analysis provided was based on the parameterization of the marginal abatement cost curves for the ETS sectors and the rest of the economy for EU MS countries.

The aforementioned approaches are considered as hybrid evaluation designs since they generate both quantitative and qualitative data and analysis. The quantitative data comprise numerical simulation results of the effects of combined policy instruments on predetermined key variables compared to the reference (i.e. stand alone policy instruments). Applying hybrid evaluation approaches in assessing energy and climate policy interactions can help to identify who benefits from the concurrent implementation of energy and climate policy instruments and who is burdened with extra costs and why. A hybrid evaluation that combines qualitative and quantitative methods can generate both a statistically reliable measure of the magnitude of the impact of interacting policies as well as a greater depth of understanding of how and why a (set of) policy instrument(s) was or was not effective and how it might be reconfigured in the future to make it more cost effective.

4. A cross comparison of different approaches, methods and views on energy and climate policy interactions

The majority of the methods applied, either within a quantitative, qualitative or a hybrid design framework tend to evaluate policy instruments and their potential combinations as a course of a rational process in the sense that they form the basis in order to identify effective and efficient combinations of policy instruments [7].

When it comes to quantitative interactions assessment, the application of energy models tend to focus on the impacts identified at a market level, adopting a view on policy interactions that relate to the motives and the nature of the stakeholders and interests involved who look for the best possible solutions (see Fig. 3). Optimization analytical methods adopted by energy models are used to optimize energy investment decisions endogenously. The outcome represents the optimal solution for given variables, while meeting the given concurrent constraints of policy instruments implemented in parallel.

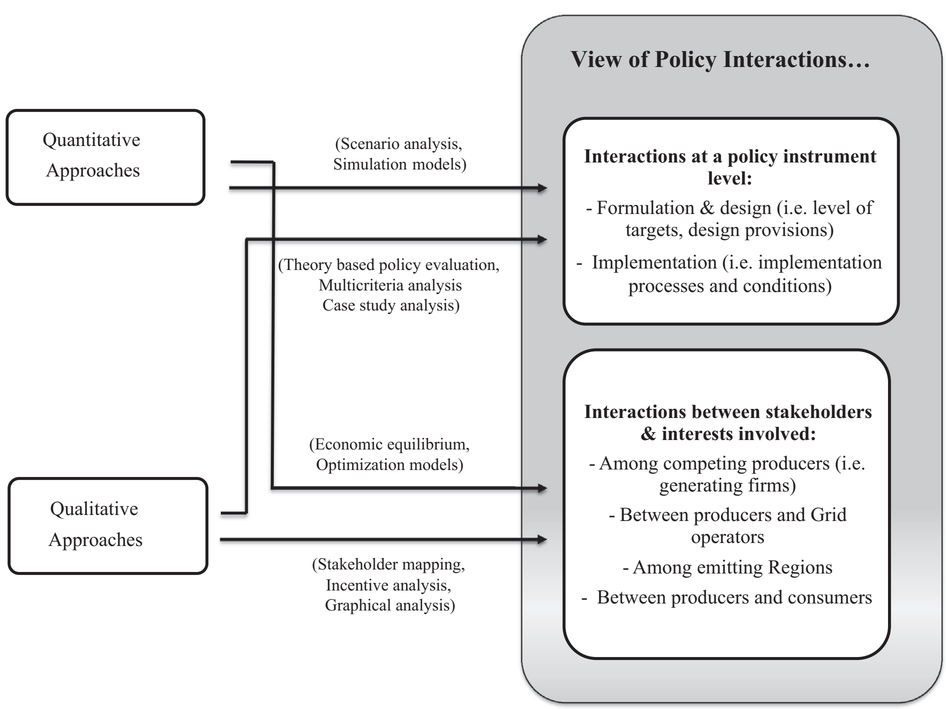

Fig. 3. Principal evaluation approaches and assessment methods towards policy interactions assessment.

Optimization is usually used by competing electricity generating firms (i.e. energy producers), grid operators or municipalities to derive their optimal investment strategies [42,63,12]. Similarly economic equilibrium analytical methods, tackle energy and climate policy interactions also at the level of equilibriums between energy demand and supply (i.e. partial) or are concerned with the conditions (i.e. constraints) that allow for simultaneous equilibrium in all markets (i.e. general equilibrium) [25].

Energy models, applying policy scenario analysis complemented by numerical simulations, have mostly dealt with the issue of the relative stringency of coexisting policy instruments and its microeconomic and offsetting impacts on one another by simulating scenarios with different targets being set. Simulated scenarios generate outcomes upon different variables such as carbon reduction, CO_2 emissions, electricity generation mix [2], production levels of different fuel types [58] or upon renewables penetration [49]. Evaluation of policy interactions is seen as an assessment of policy outputs[3] owing to the coexistence of policy instruments.

Few attempts have been made to account for issues that relate to, alternative design provisions of policy instruments and resulting implications. Indicatively Gawel et al. [16] investigated the influence of different policy objectives on the overall social costs of policy intervention, while Morriss [37] accounted for additional costs (i.e. administrative and transaction costs) of existing policies in the modeling formulation.

On the other hand, qualitative research is not only limited to assessing achieved effects of and resulting policy products due to different policy combinations. Instead recent qualitative analyses of energy and climate policy interactions turn their focus on exploring the conditions under which a policy package is functioning or not. Theory based evaluation draws on the theory of policy implementation steps and identifies cause impact relationships and success factors referring to the response of targeted industry groups to the respective energy and climate policy package, considering also interrelationships with other instruments in the package. Like so, Harmelink et al. [19], when applying an ex-post theory-based policy evaluation of energy efficiency policy instruments identified conditions under which policy combinations are required as well as conditions of policy redundancy in terms of existing policy potential for development and market transformation. These conditions relate to challenges in addressing different target groups, addressing different scopes (e.g. sector, different technology features), financial, institutional, and knowledge barriers, internalizing externalities (i.e. external costs), and addressing market competition.

Another method widely applied to support qualitative evaluations of interacting policy instruments in their specific context of implementation is case study analysis explaining how a policy instrument as a part of the policy mix, is functioning and why. Accordingly, Ropenus et al. [52] provided an ex-post historical evolution of RES support policy instruments building on country-based analysis of the different regulatory areas in five selected Member state countries. The case study analysis was applied to weigh up different policy alternatives of RES support instruments and network regulation on distributed electricity generation. In this way increased credibility supports the conceptual analysis of the interaction effects of policy dimensions of connection charging regimes and RES support policies providing a qualitative understanding of the latter.

Qualitative research is also largely driven by the same rational view of interactions that of interrelationships among targeted stakeholders and interests involved. Stakeholder mapping and incentive oriented analysis offer useful frameworks for explaining and assessing the choice of different policy combinations, including understanding of the effects of alternative policy design features in policy overlaps. Transaction costs originating from the combined policy life cycle, baseline constructions and the issue of additionality are some of the policy instrument design specifics due to which combined energy efficiency policy instruments may overlap (i.e. double counting or double coverage) or act in synergy. These effects are likely to be identified via graphical incentive analysis and market mapping methods [56,43].

As a final point, only a few examples [54,44] of research in the field of policy interactions have incorporated alternative pluralistic paradigms of policy evaluation. Participatory methods elicit more qualitative and interpretive information and are used to improve outsiders' understanding of complex policy context [14] and provide significant insights in the field of policy interactions helping to explain contextual differences in the quality of policy interrelationships. A detailed analysis of recent studies on evaluating energy and climate policy interactions is provided in Appendix A of this review.

5. Impact focus and efficacy factors behind the impact

Recently a number of reviews have addressed the area of research for interacting policies primarily looking at potential consensus and conflicts among ensuing outcomes of policy interrelationships [13,22–24,41,10]. The following section reviews the impact focus of evaluation studies based on the principal evaluation criteria identified in the assessment framework (see Section 2). Special attention is paid to what types of factors, determining the efficacy of policy instruments, have been ascertained by research in the field of energy and climate policy interactions.

5.1. Impact focus when assessing interaction in the energy and climate policy mix

In terms of effectiveness, mainly environmental benefits and microeconomic impacts of interacting policies have been addressed quantitatively through exploratory scenarios examining the impacts of RES support and carbon policies upon key market variables, by and large represantive of targeted stakeholders' costs and profits (e.g. carbon emitting firms, consumers, electricity producers, etc.) ([1,2,8,20,37,35,49,58]). Change in welfare (i.e. welfare loss) due to the imposition of an RPS instrument on top of an existing Cap and Trade system has been identified mostly with the application of CGE models. Simulations showed an increase of welfare loss due to a more costly generation mix in the short term (i.e. until 2030) which is however decreased in the long term, since investments in renewable technologies in the later years bring down costs [1,37].

Similarly effectiveness and efficiency have been and still remain the focal points in the bulk of qualitative approaches as well [17]. Effectiveness in terms of macroeconomic impacts and environmental benefits of combined policy instruments is most frequently translated into market price signals, energy effectiveness (e.g. energy security of supply), RES-E and EE investments, etc. [13,26,42,44,45,52,9,11,55]. On the other hand impact analysis in qualitative approaches is a lot more extensive mainly due to the wide application of multicriteria analysis that tries to incorporate all (conflicting) criteria simultaneously within the analysis [7].

Finally although researchers have adequately analyzed the performance of interacting policies in terms of effectiveness and efficiency, social effects and costs (e.g. employment generation) on the other hand have not been analyzed as extensively [3]. Social impact assessment has scarcely been addressed with energy simulation models, as changes in consumer's and producers'

[3] Policy outputs are considered to be the products, capital goods and services which result from a policy intervention; may also include changes resulting from the intervention which are relevant to the achievement of outcomes (Gabardino and Holland, 2009).

Table 1
Contribution levels of qualitative and quantitative approaches in the impact assessment dimensions of interacting policies.

Impact focus	**Effectiveness**			**Efficiency**	
Evaluation approach	Environmental effectiveness	Economic opportunities and competitiveness	Social effectiveness	Static efficiency	Dynamic efficiency
Quantitative					
Qualitative					
NOTE: Darker shading indicates a high contribution level of evaluation approaches to the respective impact(s); lighter shading indicated a medium contribution of approaches in addressing the impact and no shading indicated a low level of contribution.					

surplus due to the incidence of overlapping RES and carbon reduction policy instruments [2]. Societal effects in terms of improved quality of life, strengthened empowerment and enhanced prosperity have been raised and addressed more frequently than quantitative approaches, in terms of social equity, social costs and political acceptability, or through the standard measure of consumer and producer surplus in qualitative frameworks of policy interaction impact appraisal ([54,56,44]). Sorrell and Sijm [55] in their attempt to explore the justifications of inducing EE promotion policies argue that rationales supporting employment benefits are not so persuasive as jobs are being frequently created in priority sectors and locations, while economists suggest that the cost effectiveness of this employment creation is relatively small [53]. Table[4] below (Table 1) summarizes a qualitative evaluation of the contribution level of qualitative and quantitative approaches in the impact assessment dimensions of interacting policies.

Regarding costs related to technology and innovation push, model based approaches have also started to incorporate operations & maintenance fixed and variable costs for a more accurate representation of compliance costs of proposed combined policy instruments ([37,49]).

With the same focus, Del Rio [11] applied a multicriteria analysis framework to evaluate proposed instruments against their dynamic efficiency, i.e. their ability to generate continuous incentive for technological improvements. With the same objective on the costs of investing in innovation and new technology deployment support combined policies, Levinson conducts a meta-analysis of past research to argue that investment in R&D should be carefully addressed as empirical results demonstrate that the industry-wide return to R&D is just about two to four times as high as the returns to any other firm, implicating underinvestment in R&D [27,34].

Overall energy and climate policies tend to focus on the energy sector although they influence society, economy, environment and technology to a great extent [3]. Impacts of policy combinations upon societal welfare, technology costs and innovation can be uncertain or sometimes even greater. As such it becomes imperative that future research emphasizes on social and technology impacts into their analytical frameworks.

5.2. Efficacy factors behind the impact of the energy and climate policy mix

As already discussed (see Section 2) deviations between the intended and observed policy course and effects may be attributed to unexpected circumstances and conditions. In this section we seek to identify to what extent, such information have been incorporated in evaluation approaches of policy mixes so far and provide a comparative overview of the most significant factors identified (or not) by each approach in order to enable a more realistic assessment of the effectiveness of policy instruments in the future.

When it comes to general contextual factors, related to the national context where RES support and climate policy instruments are being imposed, the majority of energy system models are likely to incorporate significant market parameters, determinants of supply and demand equilibrium simulated for the energy market. Those factors influence the extent of the effects of the simultaneous implementation of policy instruments that usually relate to generating extra costs or revenues for the associated market players ([1,35,37,2]). On the other hand, energy economy models, as already stated (see Section 3), tend to provide a less detailed representation of the energy system focusing on the comprehensiveness of endogenous market adjustments.

Like so, a partial equilibrium model simulating equilibriums for 21 regional electricity markets (i.e. United States) was employed by Palmer et al. [49] to analyze how RES and Cap and Trade policies affect the generation mix, electricity prices and consumption, and greenhouse gas emissions at both the national and regional levels. Each region was classified based on its method for determining electricity prices and reserve services as either market-based competition or cost-of-service regulation. The findings showed that the electricity price effects of policy instruments depend on the regulatory structure of electricity markets, which varies across each state.

Apart from economic factors, Fankhauser et al. [12] speak about the political context in which policy instruments are imposed, in an effort to identify effects and associated costs resulting from the

[4] The qualitative evaluation of the contribution levels of approaches was based on a detailed analysis of the sum of research studies under review against the effectiveness and efficiency criteria. The shadings were the outcome of a comparison of impact assessment dimensions addressed by the sum of qualitative and quantitative research studies. The detailed tables of the aforementioned analysis are available upon request.

Table 2
Overview of efficacy factors considered in impact evaluations of energy and climate policy interactions.

Efficacy factors identified behind the impact of energy and climate policy mixes		
Quantitative evaluation design	**Economic and political context** 1. Electricity market structure and design 2. Interconnection of domestic electricity markets in Europe 3. Primary factors: labor, capital, conventional and non-conventional resources 4. Supply & demand parameters 5. Incumbent policy framework included in the reference scenario 6. Different RES penetration levels 7. RES potential 8. Efficiency of the whole electricity system (grid loss from production to transmission and distribution) 9. Emissions of other (than GHG) air pollutants 10. Discount rate for investments 11. Firm behavior 12. Allowance trade patterns among regions	**Policy cycle** **Design** 1. Trading option (i.e. certificates, allowances) 2. Banking of emissions 3. Alternative compliance payments 4. Distinctions between price-based or quantity-based policy instruments with variations in prices and quotas for commodities (i.e. stringency levels) 5. Uniform/Differentiated Feed in Tariff scheme per technology type 6. Phase in of Renewable Portfolio Standard 7. Annual digression rate of Feed in Tariff rate 8. Limitation of the payment period 9. Tariff reduction due to inflation **Implementation** 10. Technology specific hurdle rates reflecting market barriers, consumer preferences and risk factors limiting purchase of new energy technologies)
Hybrid evaluation design	**Economic and political context** 1. Socio-demographic and lifestyle trends 2. Interconnection of domestic electricity markets in Europe 3. Political context in which policy instruments are imposed 4. Supply & demand parameters 5. Firm behavior	**Policy cycle** **Design** 1. Distinctions between price-based or quantity-based policy instruments with variations in prices and quotas for commodities 2. **2.**International emissions trading 3. Uniform and unilateral imposition of carbon taxes across all EU ETS regions 4. Lump-sum treatment of additional tax revenues 5. Stringency levels 6. Different application scope (upstream/downstream) **Implementation** 5. Conditions for implementation and proper utilization of saving options: – Technology/equipment availability – Familiarity with the policy – Overcoming barriers (remaining lifetime of the existing energy using systems, the split incentive between ownership/investment) – motivation to invest 6. Specific implementation of policy instruments with regard to their funding (i.e. by the government or by end-users). 7. Transaction costs 8. Stability & credibility in the policy regime
Qualitative evaluation design	**Economic and political context** 1. Simplifications in technology production options and load segments of electricity production 2. Limited analysis of constraints in output 3. Slope of demand & supply curves 4. Electricity market structure and design 5. Technology market failures and other externalities related to electricity generation design	**Policy cycle** **Design** 1. Nature of targets, the target groups, the policy-implementing agents, the available budget, the available information on the initially expected energy savings impact, and the cost effectiveness of the instrument. 2. Distinctions between price-based or quantity-based policy instruments 3. Different RES-E support design elements: FiTs: fixed premium versus tariff, floor, cap, support tied to electricity prices; stepped FIT (technology-specific); digression, banking and borrowing; TGCs: immature technologies excluded, low penalty, minimum prices, existing plants non eligible, technology specific quota 4. Variable scenarios in the short and long run for key policy parameters such as price of certificate, level of obligation, level of sales tax and the level of penalty 5. Fixed-price policies (those in which the price variable is chosen directly) and endogenous price policies (markets set the effective taxes or subsidies through the values placed on tradable credits) **Implementation** 6. Implementation period of the policy instrument 7. Circumstances in which to apply a policy instrument – Challenges (e.g. behavior, size characteristics) in addressing different target groups, – Challenges in addressing different scopes (e.g. sector, different technology features), – Addressing a financial, institutional, knowledge barrier, – Internalizing externalities (i.e. external costs), – Addressing market competition (e.g. low hanging fruits), – Conditions under which a policy combination is required and – Conditions of policy redundancy (i.e. incumbent policy potential for development and market transformation).

Table 2 (*continued*)

Efficacy factors identified behind the impact of energy and climate policy mixes	
	8. Implicit and explicit assumptions in the policy implementation process and mapping the cause–impact relationships. 9. Transaction costs related to the combined policy cycle 10. Regulatory decisions on the additionality of energy savings from individual projects: – Environmental additionality/financial additionality – Fixed Baseline/dynamic baseline – Crediting lifetime

[a] Representative examples of such parameters identified within recent modeling studies are rich technology mix, generating costs per technology type, maximum capacity per generating unit, reserving generating capacity, slope of energy demand & supply curves, RES intermittency, different RES penetration levels, CO_2 emissions rate per generating type, different load segments in electricity production, substitution possibilities among energy and other commodities, cost-disadvantage for initially inactive technologies and capacity limits due to technological and political constraints. For instance it is demonstrated that the magnitude of the price signals of cap and trade policies largely depend on whether emissions allowances are allocated by auction or by grandfathering.

Table 3
Quantitative and qualitative dimensions in energy and climate policy interactions appraisal.

Quantitative evaluation	Qualitative evaluation
1. Numerical data estimating the extent of policy combination impacts 2. Forecasting of outcomes of interacting policies on market-relationships 3. Work best for narrowly specified policy combinations 4. Sufficient market and technology details representing supply and demand equilibriums 5. Enhanced support of effectiveness and efficiency judgments in policy combinations 6. Intertemporal evaluation framework (short to mid-term, mid to long-term)	1. Descriptive explanatory analysis of often non-quantifiable processes in policy interactions 2. Explanation of contextual differences and cause impact effects 3. Appraisal of diversified and complex policy interactions 4. Focus on the role of implementation context and design characteristics in the effects of interacting policies 5. Easier to integrate participatory analysis allowing for a better understanding of assumptions and key structural relations. 6. Intratemporal evaluation framework

concurrent implementation of climate policies. He points out to the fact that the combination of climate policies may result in spending scarce political capital with very low abatement effects to reason it; by serving an artificial perception that “more is being done”.

In such a complex policy setting, qualitative approaches mostly contribute to the assessment of the diversity of different design characteristics of policy instruments and to the complexity of policy interactions influencing the effectiveness of the (set of) policy instrument(s) under assessment in relative terms. Qualitative approaches, due to their exploratory focus tend to concentrate on the identification of typical circumstances in which to apply a set of policy instruments (Boonekmap, [6]; Harmelink et al., [19]), allowing for complex analysis of often non-quantifiable cause-and-effect processes during the design and concurrent implementation of policy instruments.

As such, qualitative approaches such as INERACT project [54] addressed a variety of design and implementation features affecting the impacts of policy combinations. Administrative simplicity in terms of administrative burden on the target group, the implementation organizations, political acceptability, and compliance measures were some of those highlighted within the intratemporal assessment framework. Likewise Oikonomou et al. [43], when exploring the potential of a proposed policy instrument of a voluntary agreement (VA) with a TWC considered in detail the institutional setup of interacting policy instruments under assessment that is regulated bodies for the set up, administration, verification and registration of the individual policy instruments. He considers the proposed combination of policy instruments to be overlapping with regard to its institutional setup, if different institutional bodies are assigned to regulate each policy instrument owning to the reduced administrative simplicity and co-ordination.

Information of economic trends governing the implementation of policy instruments is rather straightforward in the majority of qualitative approaches. Such studies exploring how market and economic trends affect environmental and welfare impacts of interacting policy instruments tend to provide explanatory representations by focusing on a small number of price, quantity and distributional variables. The impacts of policy instruments on each variable are explored through simple trend analysis and graphical techniques [56]. Table 2 below provides a comparative overview of factors considered in recent evaluation approaches of energy and climate policy interaction.

Although qualitative approaches such as multicriteria analysis are able to include several variations and details related to the design and implementation characteristics of interacting policy instruments [43,44,54] they develop an intratemporal evaluation framework accounting for only current effects of combined instruments.

On the other hand, quantitative approaches have mainly explored how interaction impacts vary based on the distinction between price-based or quantity-based policy instruments with variations in prices and quotas for commodities, trading and banking options. The importance of flexible design mechanisms, in terms of providing corresponding abatement options to the target groups have also begun to gain attention in quantitative research in the field. An alternative compliance payment mechanism incorporated in a RPS policy instrument seems to substantially affect renewables penetration [49] while Morriss [37] points out that by removing the flexibility to pursue the least costly emission reduction strategy, a RPS policy instrument becomes significantly more costly.

In one of the first studies to evaluate interacting policy instruments within a hybrid evaluation design, allowing for more empirical based examination, Boonekamp [6] assessed the contribution of different energy efficiency policy instruments to the conditions for implementation and proper utilization of saving options; by examining whether the policy instruments in question are available for application, known to appliers, lift potential restrictions and provide motivation to investors. Finally, Palmer et al. [49] acknowledged the fact that "The efficacy and cost-effectiveness of different policy approaches depend on the combination of policies that are adopted, the particulars of the policy design, and the goals that the policies seek to achieve".

Overall the integration of socio-political (e.g. socio-demographic and lifestyle trends, political context) and environmental factors (e.g. RES penetration levels, emissions of air pollutants, etc.) in addition to economic ones, in accordance with the geographical characteristics and the electricity market structure of the area under assessment, would allow for a broader analysis of interacting policy instruments by identifying potential market failures and hurdles to socio-economic development that extend over time [3]. As a final point longer evaluation timeframes are essential in order to account for policy implications such as delays and impeding factors in the implementation process, policy resistance and redundancy elements that usually extend over time.

6. Concluding remarks

The additional aspects of quantitative and qualitative research are summarized below, fitting into our original definitions, which described the types of data and analysis produced. A set of six dimensions that characterize the two traditional evaluations in the field of energy and climate policy interactions is presented in Table 3. These broader aspects consist of useful points of reference when we consider the potential of different approaches to allow for an integrated evaluation of complexity inherent in policy interactions and resulting market implications.

Overall qualitative design frameworks contribute to the assessment of the diversity and complexity of policy interactions affecting the impacts of policy instruments to be assessed in relative terms, whereas modeling (i.e. quantitative) approaches provide absolute numbers and economic trends that affect them.

Regarding untapped issues in recent research approaches assessing overlapping energy and climate policies we argue that the issues summarized above need to become the focal points of the research to follow.

- A large share of recent approaches apply a partial equilibrium approach to frame their analysis, address the multi-actor and multi-level nature of interacting policies to a limited extent. They mostly adopted a rational view of policies and policy interactions leaving out a systemic evaluation of the institutionalism of interacting policies.
- Diversity in the assessment of policy combinations is still narrow. RES-E support and carbon policies are easier to quantify unlike energy efficiency ones that are not as mature in the market lacking of significant data and information.
- Research in significant inter-sectoral interactions of energy and climate policy instruments with other environmental policies still remains untapped since evaluation approaches are mainly focused on the energy sector.
- Regarding sustainability within impact assessment of overlapping policies, the social and technological dimensions have scarcely been examined. Especially social impacts of interacting policy instruments, which are not reflected in price signals, supply and demand curves, or in the large economic measures of inflation, gross domestic product, and other measures of aggregate demand and savings need to be assessed via meso-economic thinking.
- Ex post evaluation can reflect to a higher extent reality whereas ex-ante is more restricted denoting that it projects impacts of policy interactions compared to a speculative future scenario and estimates the results against a set of fixed criteria [39,42]. Only a few approaches ([54,6]) manage to incorporate both views in conjunction testing their theoretical analysis with empirical observations.
- A hybrid evaluation that combines ex-ante qualitative and quantitative analyses based on empirical observations, can generate both a statistically reliable measure of the magnitude of the impact of interacting policies as well as a greater depth of understanding of how and why a (set of) policy instrument(s) was or was not effective and how it might be reconfigured in the future to make it more efficacious and cost effective in the end.
- The political context is often not included in evaluation approaches, especially quantitative ones and significant side-effects regarding (i) useless political funds for insignificant environmental benefit, (ii) altered distributional effects and equity issues, (iii) emasculated regulators' credibility that may result in more policy intervention (Fankhauser, [12]) are not considered all together. Participatory analysis has been incorporated into almost all stages of individual policy design and evaluation, and would provide significant insights in the field of energy and climate policy interactions regarding the political context of implementation.
- There is an increasing effort from researchers to switch from static representations to longer term evaluation timeframes generating less interim results concerning the impacts of overlapping policies by encompassing market dynamics, future socio-political trends as well as delays and implications during their implementation that usually extend over time.

All things considered, one may argue that in practice, the analysis of efficacy would be related to those cases where one policy instrument or mix of policy instruments shows different degrees of effectiveness in countries or different sectors. It is yet the ease of difficulty of implementation that can play the decisive factor for its effectiveness altogether. Endeavors for an improved methodological framework that would allow for an orderly exchange of data between qualitative and quantitative approaches and would also include the relevance of the context as well as key casual relationships behind policy combinations, would provide the basis for further growth of knowledge in the field.

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Appendix A

See Tables A1–A5.

Table A1
Outline of quantitative approaches.

Energy model category		Study	Approach	Bottomup/ topdown	Evaluation timeframe	Type of assessement	Case study based	Sectors included
Energy system models		**i.** [35]	Generation expansion model/linear optimization	Both	Intertemporal short to mid-term (2005–2020)	ex-ante	Yes (Spanish power sector)	End use sectors (services, industry, transportation, households)
		ii. [1]	Computable general equilibrium (CGE) model	Both	Intratemporal	ex-ante	Yes (Germany)	**Non-energy** (agriculture, mining, manufacture energy intensive industries, services, transport) **Energy** (electricity, coal, natural gas, gas crude oil, refined oil)
		iii. [37]	Computable general equilibrium (CGE) model	Topdown	Intertemporal longterm (2005–2050)	ex-ante	Yes (UnitedStates)	**Demand sectors:** Agriculture, energy-intensive products, other industries products, services, transportation, household transportation, other household demand **Electric generation:** conventional fossil, hydro, nuclear, wind, solar, biomass, advanced gas (NGCC). Advanced gas with CCS, wind with gas backup, wind with biomass backup**Fuels:** coal, crude oil, shale oil, refined oil, natural gas, gas from coal, liquids from biomass, synthetic gas
		iv. [12]	MARKAL elastic variant (MED) model/linear optimization	Bottomup	Intertemporal long term (2000–2050)	ex-ante	Yes (UK)	Hydrogen, electricity,transport services, residential, industry agriculture
		v. [17]	Integrated MARKAL-EFOM system model/linear optimization	Bottomup	Intertemporal short to midterm (2005–2020)	ex-ante	Yes (Germany)	Energy demand sectors (industry, residential, commercial/agriculture and transport), public & industrial electricity and heat production, refineries and other fuel conversion
Energy–economy model	(Integrated)	**vi.** [49]	Haiku partial equilibrium model/non-linear optimization	Topdown	Intertemporal longterm (2010–2035)	ex-ante	Yes (U.S. federal states)	Regional electricity markets and interregional electricity trade
		vii. [12]	Partial equilibrium/linear optimization	Topdown	Intratemporal	ex-ante	No	Electricity sector
		viii. [4]	Partial equilibrium/linear optimization	Topdown	Intratemporal	ex-ante	No	Closed power market
		ix. [33]	Partial equilibrium/linear optimization	Topdown	Intratemporal	ex-ante	No	–
		x. [42]	Partial equilibrium/linear optimization	Topdown	Intratemporal	ex-ante	No	Electricity sector
		xi. [13]	Partial equilibrium/linear optimization	Topdown	Intratemporal	ex-ante	No	Electricity sector (natural gas, coal, oil and renewables)
	(set of models)	**xi.** [58]	Partial equilibrium/linear optimization	Bottomup	Intratemporal	ex-ante	Yes (California state)	Electricity generation sector

Table A2
Outline of qualitative approaches.

Study	Qualitative approach	Supporting method	Main focus – criteria	Main address	Policy types included	Evaluation timeframe	Type of assessement	Case study based
i. [19]	Theory based policy evaluation	Case study analysis	Success and failure factors identified in all of the steps in the implementation process in order to improve the impact and cost effectiveness	All parties	EE support	Intertemporal (short to mid-term)	expost	Yes (Italy)
ii. [43]	Multi-criteriabasedevaluation	–	Effectiveness, efficiency, innovation process, impacts on society	All parties (residential and commercial sector)	CO_2 emissions reduction EE support	Intratemporal	exante	Yes (Netherlands)
iii. [44]	Multicriteria decision analysis (Energy & Climate Policy Interactions (ECPI)) decision support tool.	–	Climate, energy, financial, macroeconomic, technological	Energyendusers	CO_2 emissions reduction EE support	Intratemporal	exante	
iv. [11]	Multi-criteria based evaluation	Graphical equilibrium analysis	Effectiveness, Cost effectiveness, dynamic efficiency	Electricity supply and demand	CO_2 emissions reduction RES-E support EE support	Intratemporal	exante	
v. [52]	Conceptual incentive analysis	Case study analysis	Risks and costs allocated to distribution systems operators and distribution generators/RES operators	Distribution generators, distribution system operators and RES producers	Network regulations Res-E support	Intertemporal (short to mid-term)	expost	Yes (Spain, UK, Germany, Denmark, The Netherlands)
vi. [26]	Conceptual incentive analysis	Graphical equilibrium analysis	Consumers' electricity price, Emissions reduction, RES promotion	RES-E producers thermal producers electricity consumers	CO_2 emissions reduction RES-E support	Intratemporal	exante	No
vii. [9]	Conceptual analysis (scenario building)	–	Incentives for the implementation of RE- CDM projects, RES-E deployment and sustainability benefits,CO_2 allowance prices, Welfare of electricity generators, GHG emissions, Final consumers' cost, Conventional Electricity deployment	Electricity producers, consumers in Non Annex I and Annex I countries	CO_2 emissions reduction RES-E support	Intratemporal	ex ante	No
viii. [34]	Conceptual incentive analysis	Graphical equilibrium analysis	The impact of environmental regulations that address the same pollutant, on one another, carbon prices, emissions prices and overall on abatement costs	Carbon emitting firms in the electricity sector	CO_2 emissions reduction RES-E support	Intertemporal short term	ex-post	No
ix. [55]	Conceptual theoretical analysis	–	CO_2 emissions, Static efficiency, Dynamic efficiency	Electricity consumers, suppliers, and shareholders	CO_2 emissions reduction RES-E support EE support	Intratemporal	ex ante	No
x. [56]	Theoretical analysis	Graphical equilibrium analysis	Price variables: wholesale electricity prices, retail (consumer) electricity prices, EU-ETS allowance price, white certificate price Quantity variable: electricity demand, renewable electricity generation, non renewable electricity generation, carbon dioxide emissions, investment in end user energy efficiency, investment in new renewable energy generation distributional variables impacts on el. produces, impacts, on producers of energy efficiency equipment, impact on el. consumes	Electricity producers, Producers of energy efficiency equipment Electricity consumers	CO_2 emissions reduction EE support	Intratemporal	ex ante	No

Table A3
Outline of quantitative evaluation approaches in relation to their views of interactions.

Study	Evaluation approach	View of interactions	
i. [35]	Generation expansion model/ linear optimization	**Policy instrument level: -**	**Stakeholder/market level:** The electricity market (Short term): generation firms compete in quantity of output base on their conjectures about their competitors 'strategic decisions (conjectural variations approach). In the long-term electricity market, firms compete in generating capacity with regard to various simultaneous optimizations – for each firm e, the maximization of its profits is subject to its particular technical constraints (Cournot problem).
ii. [49]	Haiku partial Equilibrium model/non-linear optimization	**Policy instrument level:** Four scenarios of policy combinations are modeled and sensitivity analysis addressing the absence of alternative compliance payment provisions of a policy is considered.	**Stakeholder/market level:** A deterministic partial equilibrium model simulates equilibrium in regional electricity markets and interregional electricity trade with an integrated algorithm for emissions control technology choices for sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury. Electricity supply is represented as a model plant according to their technology and fuel source. The operation of el. system is based on the minimization of short-run variable costs.
iii. [58]	Partial equilibrium/linear optimization	**Policy instrument level:** Comparative statics on two policy parameters, binding emissions CAP and RPS constraint, estimate the marginal effect on the market outcomes related to these two policy parameters.	**Stakeholder/market level:** To overview the interaction of markets in the co-existence of the C&T and RPS policies , three types of power producer, i.e. coal, natural gas, and renewable producers are considered, who face price-responsive electricity demand. Producers maximize their profits, which are equal to the total revenue (from the electricity or the RECs sale) minus the production cost and the payments for RECs and the CO_2 emission permits. A numerical model is then applied to take into account the spining reserve market that compensates for uncertainty in wind production. Monte Carlo simulations are employed to examine the distribution of the potential market outcomes.
iv. [1]	Computable general equilibrium (CGE) model	**Policy instrument level:** The impact of a pure emission trading policy instrument and two renewable support schemes on generation investment and market prices is identified.	**Stakeholder/Market level:** Each technology is characterized by a Leontief unit input vector of capital, labor, and fuel input. Each technology is associated to base, mid, or peak load and within the load patterns technologies are perfect substitutes.
viii.	computable general equilibrium (CGE) model	**Policy instrument level:** Adding the various levels of renewable portfolio standard requirements to the cap-and-trade policy	**Stakeholder/market level:** Each technology is represented by constant elasticity of substitution (CES) production functions input vector of vector of capital, labor, and fuel.
x. [2]	MARKAL elastic variant (MED) model/linear optimization	**Policy instrument level:** Exploratory analysis of the interactions of intermediate renewable policy (renewables obligation, renewables transport fuel obligation, and renewable heat program for buildings) on long-term carbon reduction targets	**Stakeholder/market level:** Demand functions determine how each energy service demand varies as a function of the market price of that energy service. A combination of the proportional change in prices and the elasticity parameter (E) determines the changes in the energy service demand according to the step amount. The model maximizes producer surplus and consumer surplus by including the cost of demand reduction in the objective function.
xi. [2]	The German TIMES (integrated MARKAL-EFOM system) model /linear optimization	**Policy instrument level:** Variation of – ETS emission reduction targets – integration of the FIT system for renewable electricity	**Stakeholder/market level:** A deterministic approach is used to endogenously model the tariff system by integrating the tariffs directly into the model and by assigning the corresponding levy to the end-use electricity prices through an iterative process of several model runs.
ix. [4]	Partial equilibrium/linear optimization	**Policy instrument level:** A combination of technology-specific production subsidies to green producers and a tax on electricity consumption setting a binding share of green emissions in black production is imposed on a binding emissions trading system.	**Stakeholder/market level:** A competitive power market is considered, with renewable producers and producers of conventional power, where government has imposed a binding cap on total emissions from the power sector and a green quota which requires a binding share of total power production to be covered from green power. Producers maximize their profits subject to the policy constraints that may generate extra costs or revenues.
x. [12]	Partial equilibrium/linear optimization	**Policy instrument level:** Simultaneous taxes and cap-and-trade (hybrid policy instruments): – Tax and trade – Trade and subsidy (permit trading system with a per-unit subsidy) – Trade and trade (two overlapping permit-based systems) – Standards (Renewable portfolio standards) and Trade With different assumptions (asymmetric policies where the second policy instrument applies only to a subset of firms or geographies): – Unilateral tax and trade – Technology policies and trade	**Market stakeholder level:** Policy instruments that subject firms to multiple types of regulation at the same time are described as simultaneous and overlapping. Carbon-emitting firms' behavior is represented as an optimization problem, where each firm minimizes abatement costs, subject to different policy combinations affecting their marginal abatement costs.
xii. [33]	Partial equilibrium/linear optimization	**Policy instrument level:** – Microeconomic approach of interactions between three objectives and three instruments: a tax on emissions from fossil fuel, a subsidy on renewable production, a subsidy on energy efficiency. – Signs of the partial derivatives of both energy types, energy savings and market price with respect to variations in policy instrument levels (tax, RES and EE subsidy)	**Stakeholder/market level:** Two energy types, the energy from a fossil fuel and renewable energy are combined to cover an exogenous demand in energy (D). This energy is assumed to be consumed through a non-specified energetic vector (e.g. electricity) in order to satisfy a service such as lighting, transportation or heating. Thedemandcanbereducedbyenergyefficiency investments.
xiii. [42]			

Table A3 (*continued*)

Study	Evaluation approach	View of interactions	
	Partial equilibrium/linear optimization	**Policy instrument level:** Different sorts of taxation combined with WhC lead electricity suppliers to different optimizing behaviors: - el. producers under a carbon ax - el suppliers under an electricity tax - el. suppliers with a WhC obligation - el producers under a carbon tax and el. suppliers with a WhC obligation -el suppliers under an electricity tax with a WhC obligation	**Stakeholder-market level:** The behavior of energy producers and suppliers in three market conditions: (a) a policy free environment, (b) a carbon tax on fossil fuels as input for the electricity producers and a tax on sales for electricity suppliers (electricity tax), and (c) a WhC obligation for electricity suppliers. The two markets (i.e. el. production and el. supply) are presented separately in the analysis since: – efficiency loss ratio in transmission and distribution of energy – wholesale market price and retail price differ because they belong to different markets where the output of one feeds into the other.
xiv. [13]	Partial equilibrium/linear optimization	**Policy instrument level:** – A price on carbon, a tax on fossil energy sources, and a production subsidy for renewables. – Different targets for RES support schemes (increased share of RES-E deployment and CO_2 emissions reduction) and implications on welfare and compliance costs. – Distinction between fixed-price policies and endogenous price	**Stakeholder-market level:** Four different types of generation are considered: baseload technologies, natural gas, other fossil fuels, and renewable energy. A general model of economic equilibrium in energy supplies and demand is applied to demonstrate how the relative slopes of these curves determine the price incidence (i.e. signal) of portfolio standards stand alone and then combined with a cap and trade scheme as well as other policies.

Table A4
Outline of hybrid evaluation approaches in relation to their views of interactions.

Study	Evaluation approach	View of interactions	
i. [6]	Conceptual analysis + Bottom up partial equilibrium model	**Policy instrument level:** All pairs of policy instruments are assessed with regard to the influence of one policy instrument on the energy saving effect of another, considering also different design characteristics. Important interaction effects identified within the qualitative assessment are quantified as to their influence on total efficiency gains among the following policies: – regulatory energy tax, – all subsidies, – regulation of gas use for space heating (building code and performance standards for new and existing dwellings).	**Stakeholders/market level: –** Energy efficiency is realized by purchasing systems or appliances with higher conversion efficiencies, or by applying demand reducing (i.e. wall insulation). – Then a cost/benefit formula (CBR) is applied to model the choice of more efficient systems and appliances or the decision to insulate dwellings. – The relation between the penetration of saving options and the CBR is modeled in the form of an S-shaped curve. – The simulation model then reproduces past energy developments, using the relationship between various policy instruments and the penetration of saving options (i.e. theoretical past trend).
ii. [8]	Graphical equilibrium analysis + regional partial equilibrium model	**Policy instrument level:** The impact of price-based and quantity-based policy instruments concerning RES-Esupport and CO_2 mitigation is modeled with influences identified on the retail electricity price, as well as the price of commodities (allowances, certificates) in relation to the stringency (i.e. binding or not) of quotas (i.e. targets) being imposed.	**Stakeholders/Market level:** A welfare maximization model of different interconnected regions is applied (the sum of consumer and producer surplus is estimated by withdrawing total costs from the total benefits involved with the power system of each region). When calculating welfare, the total amount of price – based policy instruments (premium and CO_2 tax), needs to be withdrawn from or added to the total welfare, accordingly after the maximization. Quantity-based policy instruments add a restriction to the model to enforce a certain percentage of renewables installed or a certain cap on CO_2 emissions.
iii. [5]	Theoretical (qualitative) analysis + Computable General Equilibrium model (PACE model)	**Policy instrument level:** Comparison of the before-tax and the after-tax situation: introduction of a carbon tax on top of an ETS allocation target acting as an additional reduction incentive on top of the allowance price, affects: – the level of emissions – the demand for allowances – the international allowance price	**Stakeholder/market level:** The economic effects of an exclusive cap-and trade regulation under the EU ETS are compared to an overlapping regulation where the EU ETS is supplemented with an additional unilateral carbon tax in international as well as national allowance markets. The effects on the marginal abatement costs for the respective EU member states subject to an additional carbon tax are compared to the marginal abatement costs for the remaining EU member states reflect the international allowance price (international allowance market).

Table A5
Outline of qualitative evaluation approaches in relation to their views of interactions.

Study	Evaluation approach	View of interactions	
i. [19]	Theory based policy evaluation	**Policy instrument level:** Interrelationships with other policy instruments in the EE policy package are included in the policy implementation theory of cause-impact relationships.	**Stakeholders/market level:** Cause impact relationships and success factors referring to the response of target industry groups (companies, suppliers) to the EE policy package. Rebound and spill-over effects represantive of interrelationships between market actors in response to a policy, were not taken into account.
ii. [43]	Multi-criteria based evaluation	**Policy instrument level: Policy instrument type** (mandatory/voluntary) **Objectives** (Nature of targets, direct/indirect emissions, energy or other environmental goals, timing, reference term (primary or final energy) **Scope** (obligation bound entities, sectors) **Market arrangements** (Non-obligated but eligible parties, Trading participants) **Market flexibility** (trading commodity, nature, lifetime of commodity, banking, borrowing provisions) **Accounting of environmental benefits** (Accounting of environmental benefits, Financing, Cost recovery, Government revenues raised) **Technological parameters** (Eligible technologies/project categories, Opt-in or opt-out for technologies, Accreditation ex-post or ex-ante, Issue of additionality) **Institutional setup** (Body for setting up the policy instrument, administration, verification, registration, project design, monitoring, reporting)	**Stakeholders/market level:** Market mapping of participating entities that undertake energy efficiency actions and other entities or authorities responsible for monitoring or implementing the policy instrument: – market players that receive an energy obligation under WhC – non-obligated market players (ESCOs, building companies, financial intermediaries), and – market players that can participate in negotiating a target under VAs to improve energy efficiency
iii. [11]	Graphical analysis supported by Multicriteria assessment	Identification of whether the results of the interactions vary depending on the type of policy instrument (price based or quantity based). – Adding RES-E support to an ETS – Adding EE support to an ETS – Adding EE support to RES-E support – Adding RES-Esupport to EE support Additional analysis of the impacts of the different design elements of RES E promotion policy instruments on identified interactions.	**Stakeholders/market level: –** In order to demonstrate different policy combinations against the effectiveness criteria, their impact is identified upon: CO_2 emissions, electricity demand and RES-E generation and investments. – Regarding static efficiency, the focus is set on consumer costs (as shown by variations in the retail el. price). – Dynamic efficiency is assessed by analyzing the impact on RES-E investments and on the currently least mature technologies.
iv. [44]	Multicriteria decision analysis	**Policy specifics level:** Policy makers express in a merit order the significance they attribute to design characteristics of a policy instrument. Policy makers in turn assign weights on evaluation criteria expressing their preferences helping to incorporate in the analysis the political context and contextual differences in policy interrelationships. The same design elements considered in [43] are also incorporated in this approach.	**Stakeholder-market level:** Each policy instrument is broke down into its characteristics regarding also its target groups namely, obligated entities. Market flexibility for entities, eligible technologies, and additionality issues. A comparative overview of policy combinations based also on whether combined policies target the same group affecting thus distributional costs and benefits and thus market competition
v. [52]	Conceptual incentive analysis	**Policy instrument level:** The interaction of policy dimensions of connection charging regimes and support policy instruments is analyzed through a country based analysis of the different regulatory areas including case studies based on 5 EU MS (Spain, UK, Germany, Denmark, The Netherlands) leading to a comparative analysis of the implications of each country's current regulatory combinations. Network relations: shallow network charges, shallowishnetwrok charges, deep network charges support policy instruments regulation: feed-in tariff, price premium and quota system	**Stakeholder/market level:** Implications for the (partially conflicting) incentives of DG/RES producers and DSOs: – Conceptual analysis of different incentives of basic market actors(on DG producers and DSOs). – The impact of unbundling, access and network regulation as well as support policy instruments on DG producers and DSOs is analyzed based on their often conflicting incentives. The effect and trade-off upon those two basic market actors and the direction of the effect (opposite/negative impact, same/positive impact) is discussed.
vi. [26]	Incentive and graphical equilibrium analysis	**Policy instrument level:** – the use of one instrument to reach one goal, – two instruments to reach one goal, – two instruments to reach two goals simultaneously, c- effects of each scenario (i.e. stand alone policy instruments and in combination) upon demand and supply curves,	A simple market analysis of the most significant participants in the power sector (Renewable power producers, thermal power producers and consumers) and the main drivers and reactions of those participants in the parallel power, green certificates and emissions permit market is analyzed. Market principles are derived on their behavior is thus described when different policies targeting energy and climate targets come into effect.
vii. [9]	Conceptual analysis (scenario building)	**Policy instrument level:** Four policy scenarios are developed: – ETS in Annex-I, no CDM (Clean Development Mechanism projects) – CDM, ETS, no TGC policy instrument – CDM, ETS, TGC policy instrument in AIC (annex I countries) – CDM, ETS, TGC policy instrument in AIC. Breaking fown of those instruments into their principal design aspects: Type of instrument: (market instrument – project-based/quantity based), aim (Cost-effective GHG mitigation and sustainability of non-Annex I countries/cost-effective deployment of RES-E), target sector, relevant actors, territorial scope (international/national), unit of commodity. additionally possibilities to link the separate commodities (i.e. TGCs and CO_2 allowances) are considered: full fungibility, one-way fungibility and complete separation.	**Market Stakeholder level:** Analysis of relevant actors targeted by each policy instrument – project proponent, investor party, host country government, designated operational entity and, CDM executive board – demand side; obligated actors: consumers, suppliers – supply side: generators, public authority The TGC and CER (certificate emission credit) markets are separated. The impact of policy scenarios on several variables according to the interests of the abovementioned actors in both countries is discussed and compared: – Incentives for the implementation of RE-CDM projects countries – RES-E deployment and sustainability benefits – conventional electricity deployment – final consumer costs
viii. [34]	Incentive and graphical analysis	**Policy instrument level: – quantity regulations:** tradable emission permits (Cap and trade policy instrument)	**Market Stakeholder level:** Graphical analysis of marginal abatement costs of polluters and meta analysis of rationales behind introducing combined policy instruments.

Table A5 (*continued*)

Study	Evaluation approach	View of interactions	
		– **Price regulations**: regulatory standards – market based and non-market based – cost levels of introducing each policy type – abatement levels incurred by each policy instrument	Possible changes in abatement costs are discussed based on the price signals of combined instruments compared to the price signals of standalone instruments.
ix. [55]	Conceptual theoretical analysis	**Policy instrument level:** – Cap-and-trade ETS+carbon/energy taxes; – support policy instruments for renewable electricity; – non-price instruments to overcome barriers to energy efficiency **Design specifics:** A distinction is made between – **Directly and indirectly affected target groups:** Downstream/upstream implementation of an ETS: within a downstream policy instrument a distinction is made between direct and indirect treatment of electricity emissions). – Auctioning and free allocation of emissions Additionality issues are also discussed in terms of double regulation and double counting leading to either double coverage by a policy instrument or double counting. – The scope of each instrument (sectors, sites, portions of sites, and individual emission sources), objectives, operation (aggregate effect of the different obligations and incentives when applied in combination), the implementation (scope for rationalization and harmonization or regulatory responsibilities), timing (responses to 'triggers' and the scope for policy sequencing).	Market stakeholder level: Distinction between direct (directly targeted groups) and indirect(indirectly targeted groups) policy interaction: –Direct interaction is where the target groups directly affected by two policies overlap in some way – Indirect interaction occurs when a target group is indirectly affected by one policy and either directly or indirectly affected by a second. – Trading interaction is where two policies influence one another by the exchange of an environmental trading commodity
x. [56]	Graphical equilibrium analysis	**Policy instrument level:** Price and quantity effects are identified for – the EU ETS alone, compared to no regulatory intervention, – the EU ETS and TWC policy instrument in combination, compared to no regulatory intervention and – introducing a TWC policy instrument (i.e., the effect of the instrument combination compared to the EUETS alone).	**Market Stakeholder level:** A market for energy efficiency policy instruments (competitive, measures supplied at marginal cost), is considered parallel to the electricity market. Households are assumed to purchase the combination of electricity and EEM that maximize their welfare. Firms and commercial organizations are assumed to purchase the combination that minimizes their production costs.

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